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APPLICATION FOR LETTERS PATENT

Title : METHOD AND APPARATUS FOR PRODUCING DIRECT REDUCED  
IRON WITH IMPROVED REDUCING GAS UTILIZATION

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RELATED APPLICATIONS

This is a continuation-in-part of copending provisional application serial number 60/075,313, filed February 20, 1998.

FIELD OF THE INVENTION

5           The present invention relates to a method and apparatus for the production of prereduced iron ore, Direct Reduced Iron (DRI), or the like, in an reduction system comprising a reduction reactor, a source of natural gas, which is transformed in the operation of said system by means of a reformer and/or by the catalytic action of the metallic iron within said reduction reactor, to a reducing gas having carbon monoxide and hydrogen as its main constituents, and a heating device for heating said reducing gas prior to its introduction into the reduction zone of said reduction reactor. More particularly the invention relates to a method and apparatus which allows for a higher utilization of the chemical reduction potential of the reducing gas in the reduction system with a corresponding increase in the productivity of said reduction reactor or a decrease in the make-up quantity of gas needed for a given production level. This invention provides  
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20 a way for increasing productivity of existing reduction systems at lesser investment and operational costs as compared with the conventional alternatives of increasing the capacity of the reducing gas generator or of the known measure of installing a carbon dioxide removal system in the recycle stream of reducing  
25 gas.

BACKGROUND OF THE INVENTION

Direct reduction plants for producing direct reduced iron, known as DRI or sponge iron, hot briquetted iron, or the like (in general prereduced materials useful as feedstock for iron and steelmaking), currently produce such materials by contacting a reducing gas, composed principally of hydrogen and carbon monoxide, at temperatures in the range from 750°C to 1050°C, with a bed of particulate iron-containing material in the form of lumps, pellets or mixtures thereof. The bed of iron-containing material may be static or may be descending by gravity within a reduction reactor. Examples of such processes are described in U.S. patent Nos. 3,749,386; 3,764,123; 3,816,101; 4,336,063; 4,428,072; 4,556,417; 5,078,787; 4,046,557; 4,002,422 and 4,375,983.

It is well known that in direct reduction systems the reducing gas and the oxides being reduced reach an equilibrium which does not allow the full utilization of the reducing gas in the reduction reactor. Consequently, for efficiency the currently operating plants recycle regenerated reducing gas in order to minimize the need of make-up reducing gas. However, there has always been the need to purge or otherwise eliminate a significant portion of the spent reducing gas available to be recycled to prevent accumulation of carbon dioxide and inert elements (such as N<sub>2</sub>) in the system. The portion of gas purged normally is utilized as fuel in the reformer or gas heater of the system. This utilization as fuel recovers only the heating value of the purged

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reducing gas but not the chemical value of its costly hydrogen and carbon monoxide. If most of the chemical value, instead of being purged, could rather be utilized for reduction of iron oxides, then the amount of make up gas needed for a given level of  
5 production would be lowered, or alternatively the production would be increased for the same reformer capacity. Regeneration to upgrade the spent reducing gas effluent from the reduction reactor involves elimination of the reduction reaction products i.e. carbon dioxide and water which come out of the reduction reactor in the amounts determined by the chemical equilibrium of these products from the residual hydrogen, carbon monoxide, methane (and any other higher hydrocarbons present in minor amounts in the reducing gas).

It has long been known from a number of prior art  
15 references, for example U.S. Patent No.2,547,685 to Brassert et al; U.S. Patent No. 4,584,016 to Becerra-Novoa et al.; U.S. Patent No.4,001,010 to Kanbara et al.; U.S. Patent No.4,129,281 to Ono et al.; U.S. Patent No. 3,853,538 to Nemeth et al.; and U.S. Patent 4,046,557 to Beggs, to remove water and carbon dioxide from the  
20 reducing gas stream which is to be recycled to the reduction reactor. Water is conventionally removed by quench cooling. For CO<sub>2</sub> removal, all these patents, however, teach the utilization of a CO<sub>2</sub> removal unit, usually of the type where the CO<sub>2</sub>-containing gas is contacted with a liquid solution which reacts with said  
25 CO<sub>2</sub>, and treats the recycle gas as a whole.



These chemical absorption systems have to be provided with some source of heating, normally in the form of steam, for regenerating the solution, which requirement is costly and in some applications is not readily available. The energy needed for  
5 regeneration of the CO<sub>2</sub> absorbent solution, and the capital costs for these CO<sub>2</sub> removal units of large capacity are high.

This is to be compared with the CO<sub>2</sub> removal units of the so-called Pressure Swing Adsorption (PSA) and Vacuum Pressure Swing Adsorption (VPSA) systems, which are most preferably used according to the present invention.

The PSA type gas separation systems have also long been known. Exemplary patents are U.S. patents Nos. 3,788,037; 4,869,894; 4,614,525; 5,026,406 and 5,152,975. See also 5,833,734 and 5,858,057. These and the other patents cited herein and their  
15 content are incorporated by reference.

#### OBJECTS AND SUMMARY OF THE INVENTION

In the prior art of the direct reduction processes, there is no teaching or suggestion to recover H<sub>2</sub> (and/or CO) from the gas purge, and especially there is no such teaching to do so  
20 by using physical adsorption systems of the PSA type for CO<sub>2</sub>/H<sub>2</sub> separation. Such PSA systems rely not on a chemical reaction with CO<sub>2</sub>, but rather on activated surfaces that are selective for adsorption of specific component(s) from the gas stream. In the present invention, the PSA systems preferably used, function by  
25 adsorption of the larger molecules, particularly CO<sub>2</sub>, while

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passing mainly only the lighter  $H_2$ . Because of physical similarities, most of the CO is removed with  $CO_2$  and the heavier molecules. Perhaps because the PSA system separates desirable CO together with the unwanted  $CO_2$  from the  $H_2$ , thus the PSA use seems  
5 counter-intuitive. Nevertheless, the applicant has determined that PSA use overall has several distinct advantages over the more costly prior  $CO_2$  solution absorption systems. The use of a PSA system results in recycling more hydrogen to the reactor by treating only the purged gas and recovering therefrom the hydrogen values of such purged gas by utilization of a PSA  $CO_2$  removal unit.

This specific inventive concept also has the advantage that the unit treats a smaller amount of gas and therefore the capital costs are less, and also the regeneration of the adsorbent is made by pressure changes and not by heating (thereby requiring less energy to run). This type of gas separation produces a gas stream from the PSA unit which is rich in hydrogen, with a hydrogen content higher than 92% of the volume, which is advantageously recycled to the reactor system and used as part of  
20 the reducing gas.

The present invention thus involves recycling a first portion of the gas effluent from the reduction reactor back to said reactor and simultaneously separating for recycle a hydrogen rich gas stream from a purged second portion of said effluent gas.  
25 The separation from each other of the  $H_2$  and  $CO_2$  content of the

5 purged portion of the effluent gas in the broadest aspects of the invention can be by any separation means (including absorption) but most preferably is by PSA adsorption. The ratio of said second portion to said first portion can vary widely (including from less than 1:4 to more than 1:1).

10 In other words, the present invention is based on the principle of separating hydrogen from the portion of reducing gas which is normally removed from the reactor system as a purge (whose only past use typically has been as a high priced source of a relatively low grade fuel). The invention thus distinguishes from the prior art in that hydrogen and carbon monoxide recycling to the reduction reactor is effected in two ways: one is a direct recycling of a portion of the effluent gas and the other is a recycling of a gas stream highly rich hydrogen obtained by the separation of CO<sub>2</sub> (and necessarily CO too, when using the preferred PSA separation system) from the gas stream which is normally purged and used as fuel. By the present invention, hydrogen is recuperated and used as chemical reductant instead of only burning it as fuel.

20 It is therefore an object of the present invention to provide a method and an apparatus for producing direct reduced iron in a reduction system where quality of the recycle gas is enhanced by a more effective removal of reaction products from the recycle gas and an increase in the amount of hydrogen recycled to the reactor.

It is a further object of the present invention to provide a method and an apparatus for producing direct reduced iron in a reduction system where the productivity of said system is increased by an enhanced recycling to include hydrogen  
5 separated from the purged reducing gas (which formerly was entirely purged without recycling any useful portion thereof).

It is another object of the invention to provide a method and apparatus for either or both increasing the productivity of a direct reduction system and/or decreasing the capital investment and operational costs related to the necessary upgrading of the spent recycle gas.

Other objects and advantages of the invention will be evident to those skilled in the art or will be described in this specification of the invention and the appended drawings.

According to the present invention, the objects thereof are achieved by providing a method and apparatus by the following preferred embodiment:

A method for producing DRI which comprises feeding a reducing gas mainly composed of hydrogen and carbon monoxide and  
20 also comprising methane, carbon dioxide and water, heated at a temperature between about 850°C to about 1050°C, to a reduction reactor wherein solid particles within said reactor containing iron oxides are reduced largely to sponge iron by reaction of said iron oxides with said reducing gas; withdrawing as top gas from  
25 said reactor said reducing gas after reacting with said iron



oxides; cooling and cleaning said top gas and removing water therefrom; recycling a first portion of said top gas to said reduction reactor; removing at least CO<sub>2</sub>, preferably by a PSA or VPSA adsorption unit from a second portion of said top gas to form  
5 a hydrogen rich gas stream (with a hydrogen content preferably higher or equal to 92% by volume, and most typically higher than 95% by volume) and a hydrogen lean gas stream (usually containing mainly CO<sub>2</sub>, CO, some CH<sub>4</sub>, and residual H<sub>2</sub>); and recycling said hydrogen rich gas stream to said reduction reactor.

The objects of the invention are also achieved by providing an apparatus for producing DRI which comprises a reduction reactor having a reduction zone with a gas inlet and a gas outlet; a gas cooler in fluid communication with the gas outlet of said reduction zone; a reducing gas heater in fluid communication with the gas inlet of said reduction zone; first  
15 pumping device connected to said cooler and to said heater to recycle reducing gas from said gas outlet to said gas inlet; conduit for diverting a portion of the reducing gas effluent derived from said gas outlet of said reduction zone to a second  
20 pumping device; a CO and CO<sub>2</sub> PSA or VPSA adsorption unit for separating CO and CO<sub>2</sub> from a gas stream; and conduit communicating said second pumping device to said CO and CO<sub>2</sub> PSA or VPSA adsorption unit; and conduit to communicate said CO and CO<sub>2</sub> PSA or VPSA adsorption unit with separating with the gas inlet of said  
25 reduction zone.

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BRIEF DESCRIPTION OF THE DRAWINGS

In this specification and in the accompanying drawings, some preferred embodiments of the invention are shown and described and various alternatives and modifications thereof have been suggested; but it is to be understood that these are not intended to be exhaustive and that many other changes and modifications can be made within the scope of the invention. The suggestions herein given are selected and included for purposes of illustration in order that others skilled in the art will more fully understand the invention and the principles thereof and will thus be enabled to modify it in a variety of forms, each as may be best suited to the conditions of a particular use.

In each of the following figures, there is illustrated a PSA unit for treating the gas purged from the spent dewatered recycle gas for recovering and returning the H<sub>2</sub> component of the purge to the reactor.

Figure 1 shows schematically one of the preferred embodiments of the present invention, illustrated by a diagram of a moving bed process for producing DRI where the source of the H<sub>2</sub> and CO makeup reducing gas is a conventional "off line" steam/natural gas reformer, and the recovered purged H<sub>2</sub> is mixed back with the recycle gas fed through the heater and on to the reactor.

Figure 2 shows schematically another embodiment of the invention where the reducing gas is produced within a "self-reforming" reduction system by a natural gas reformation within



said system (where no reformer is needed and the added natural gas make up by reaction with oxidants  $H_2O$  and  $CO_2$  is transformed into hydrogen and carbon monoxide within said system, particularly within the reduction reactor by the catalytic action of the reduced iron present in said reactor), and the  $H_2$  recovered from purge gas is returned to the heater in a manner similar to Figure 1.

Figure 3 shows schematically a further embodiment of the invention plus three additional illustrative alternative variations (shown in dotted lines), where the reducing gas is produced in a  $CO_2$ -natural gas "in line" reformer and added make up natural gas is combined in the reformer with the existing oxidants  $H_2O$  and  $CO_2$  present in the recycle reducing gas. In the variations of this embodiment, the hydrogen recuperated by the PSA unit for recycle to the reduction zone of the reactor can be 1) fed to the reformer for heating (if the latter is of sufficient capacity), 2) heated in a separate heater (by-passing the reformer, useful in avoiding need to modify a reformer when upgrading an existing plant installation), 3) fed to the outlet from the reformer (relying on an oxygen-fed partial combustion for heating, reducing the size and cost of the reformer), or 4) fed to the cooling gas inlet of the reduction reactor (relying on a heat exchange with the hot DRI descending in the cooling zone of the reactor, while at least partially flowing upwardly into the reduction zone). The cooling loop shown in any of these drawings

can be omitted for those installations where the DRI is to be discharged hot for briquetting or hot charging directly to an EAF.

Figure 4 shows schematically an embodiment similar to that in Figure 2 with the difference that the natural gas feed to the reducing gas loop may be optional and there is at least a partial natural gas feed to the cooling zone, preferably with a cooling gas loop and/or a gas flow link from the cooling gas outlet to the reducing gas loop (depending on how various valves, illustrated or not, are set). In the embodiment and variations in this and the following figures the natural gas which is fed to the cooling zone cracks the methane and other hydrocarbons when contacting the hot descending DRI, allowing the deposition of carbon on the DRI and also resulting in a lighter hydrocarbons, CO, and H<sub>2</sub> gases for use in the reducing zone.

Figure 5 shows schematically an embodiment similar to that in Figure 4 with the difference that some recycled cooling gas is diverted and heated in a separate heater and feed to the recycle reducing gas at the inlet to the reduction zone.

Figure 6 shows schematically an embodiment similar to that in Figure 3 with the difference that natural gas is fed also to the cooling gas loop.

By such introduction of natural gas into the lower part of said reduction reactor as shown in figures 4-6, the resulting cooling gas stream is heated by its contact with the hot DRI within the cooling zone of the reactor and at least a significant

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portion of this gas is allowed to travel upwardly within said reactor to the reduction zone. See U.S. Patent 4,556,417.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

5 The invention is herein described as applied to direct reduction systems having moving bed reactors, but it will be understood that it can be adapted to plants having fixed bed or fluidized bed reactors. With reference to Figure 1, numeral 10 generally designates a reduction reactor having a reduction zone 12 and a discharge zone 14. Solid particles containing iron  
10 oxides 16, for example iron ore in the form of pellets or lumps, are fed to the upper portion of the reduction zone 12 and flow downwardly through said reactor 10 where iron oxides are at least partially reduced to metallic iron and are finally withdrawn typically as DRI from the reactor 10 through the discharge zone 14  
15 as indicated by arrow 18. A stream of hot reducing gas 20 is fed to the lower part of the reduction zone 12 comprising reductants like hydrogen and carbon monoxide as well as some oxidants like water and carbon dioxide resulting from the reduction reactions of said iron oxides and is caused to flow upwardly countercurrent to  
20 the descending solid particles. The reducing gas exits the reduction zone 12 at its upper part as top gas stream 22, which is cooled down with quenching water in a direct contact cooler 24. This cooling and washing with water cleans the top gas 22 of entrained dust and also condenses and separates the water produced  
25 by the reduction reactions. The resulting clean and cool top gas

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stream 26 is split into a dewatered recycle gas stream 28 and a purge gas stream 30.

The gas stream 28 is moved by a pumping device 32, which may be a blower or a compressor depending on the operating pressure of the reduction system, and is directed to a gas heater 34 before being recycled as gas stream 20 into the reduction zone 12.

Natural gas (and/or other reformable hydrocarbons) 36 and steam 38 are fed to a conventional gas-steam reformer 40 to yield hydrogen and carbon monoxide in a manner known in the art, producing a hot gas stream of reducing gas 42 which is cooled down in cooler 44 and results in a make-up reducing gas stream 46 of high reduction power. This make-up gas stream 46 is added to dewatered recycle stream 28, producing an improved cool reducing gas 48, chemically suitable for efficient reduction of iron oxides.

The other portion of cool top gas 26, namely stream 30, which in the prior art systems is a purge gas normally flared or used only unmodified as fuel in the reformer and gas heater(s), is here passed through second pumping device 50 and then treated in a Pressure Swing Adsorber unit (PSA) or a Vacuum Pressure Swing Adsorber unit (VPSA) 52, (both of which for convenience will be referred to herein generally as PSA, unless clearly indicated in the context to be the species exclusive of VPSA). The PSA unit 52 utilizes adsorbent surfaces to adsorb large molecules, mostly

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carbon monoxide and carbon dioxide from the gas stream 30 (which stream 30 additionally comprises methane, water and nitrogen), and produces a hydrogen rich stream 54 with a high volume% content of hydrogen of from about 92% to more than 99%, preferably higher than 95 volume%, and a lean stream 56 with a low volume% content of hydrogen on the order of 10% to 25% by volume. Stream 54 with the high hydrogen content comprises make-up gas which is combined with the recycled reducing gas stream 48 producing an enhanced reducing gas stream 58 with a content of hydrogen and carbon monoxide in volume% on a dry basis as follows:

H<sub>2</sub>: 50% to 70%  
CO: 10% to 17%.

The reduction potential and quality of the upgraded recycle gas stream 58 is higher as compared with the composition of reducing gas utilized in the prior art systems (even those using CO<sub>2</sub> solution absorption columns).

The temperature of the reducing gas stream 58 is raised in heater 34 to levels between about 750 to 1050°C, preferably from 900 to 950°C, suitable for efficient reduction of iron oxides. Oxygen or enriched air with oxygen 60 (having a content preferably higher than 30% in volume of oxygen) may be combined with the hot reducing gas 20 in order to obtain the higher temperatures at the reduction zone with a corresponding increase in productivity or in order to have the same productivity but requiring a lower duty in the gas heater. This productivity increase with higher temperatures is due to higher reaction rates

and also to transformation of hydrocarbons present in the reducing gas to  $H_2$  and CO by the partial combustion of the reducing gas with oxygen.

5 The lean gas stream 56 still includes among its constituents carbon monoxide and some methane, as well as small amounts of other gaseous hydrocarbons, which have heating value and may be used as fuel to fire the gas heater 34. The energy in gas stream 56 however usually is insufficient to fulfill all the heating needs of heater 34, so unreformed natural gas or other lower cost suitable fuel 62 is added to supplement said stream 56 (to produce an effective fuel supply in line 64 for the heater 34).

15 The DRI or prereduced materials 18 produced in the reduction zone 12 may be discharged at high temperatures on the order of 400°C to 750°C and can be hot briquetted or pneumatically transported to steelmaking furnaces, for example electric arc furnaces, thus reducing the energy needs in such steelmaking operations. Optionally, the DRI is cooled down in the discharge zone 14 by contact of the hot DRI with a cooling gas stream 66 comprising natural gas, a portion of the reducing gas stream 30 or stream 56, or other suitable gas which does not reoxidize said DRI. The discharge zone cooling gas effluent 68 may be cooled down and recycled as stream 66 in a manner known in the art.

25 Referring now to Figure 2, where the same numerals are used here (and in all the other figures also) to designate the



same elements as in Figure 1, this embodiment of the invention illustrates the invention as incorporated in a reduction system where the reducing gas is not generated in a natural gas-steam reformer but is generated by reformation of natural gas by partial combustion of methane present in the reducing gas with oxygen and/or by methane cracking and reformation with oxidants present in the reduction zone by the catalytic action of the iron-bearing particles in said reduction zone. In this embodiment the steam reformer 40 is dispensed with and a make up stream of natural gas 36 is instead added directly to the recycled gas stream 28, which is then combined with the hydrogen rich stream 54 to produce a combined gas stream 58. The water content in the gas stream 58 is adjusted by addition of water/steam stream 67 so that the amount of water present is between 3% and 10% by volume, suitable to be sufficient to carry out such reformation of methane within the reduction zone. This water regulation may also be effected for example as described in U.S. Patent No. 5,110,350, where the water added at 67 is advantageously taken from the hot water effluent from gas cooler 24.

Figure 3 illustrates the invention as applied to a reduction system where the reducing gas is generated in a reformer 40A of the type where natural gas from source 36 is combined with recycled gas 28 from the reduction reactor and reacts in the presence of a catalyst with oxidants such as the  $\text{CO}_2$  and  $\text{H}_2\text{O}$  present in said recycled gas. This is sometimes referred to as an

5 "in-line" reformer (as contrasted with the "off-line" reformer 40 of Figure 1; which latter reformer does not act on the recycled gas, being outside of the recycle gas loop). Examples of these "in-line" reduction systems are U.S. Patents Nos. 3,748,120 and 3,749,386. In these types of reduction systems, the reformer 40A also functions as a heater, being fed with a combination of relatively cool natural gas 36 and recycled gas 28, and the reducing gas produced exits the reformer at a temperature between 800°C and 950°C. In this embodiment, the temperature of the reducing gas may also be increased by an addition of a stream of oxygen or of air enriched with oxygen 60 in order to increase the productivity of the reduction reactor (at a small sacrifice in reducing potential of the gas 20). For existing operating reduction systems, the reformer 40A most probably does not have sufficient capacity for heating the additional amount of hydrogen rich gas stream and consequently as a supplement or alternative to O<sub>2</sub>-addition a separate gas heater 34A fed by the hydrogen rich stream 54a can be provided for this purpose (which feeds the hot hydrogen rich stream through line 70 to line 20, preferably downstream of line 60).

Figure 3, as illustrated, includes a further variation where the hydrogen rich stream 54b is heated in the reformer 40A without the need of a separate heater, assuming that the reformer has sufficient heating capacity for heating the additional amount of hydrogen rich gas. Although it is preferred to provide the



additional heater 34A (because in this way the recycled hydrogen rich stream 54a does not need to pass through the catalyst beds in the reformer 40A), in certain existing conditions it may be more feasible to design new reduction systems without said separate  
5 heater 34A.

Figure 3, illustrates yet another variation where the hydrogen rich stream 54c is introduced directly to the hot reducing gas stream 20 prior to its introduction to the reactor system without having been separately heated (thus saving the cost of a separate heater). Since the reformer 40A typically would not have sufficient capacity for heating the additional amount of hydrogen rich gas stream 54c, and the temperature of said stream 54c decreases the temperature of the reducing gas, the addition of the oxygen containing gas 60 is sufficient to increase the  
15 temperature of the hot reducing gas stream 20 to the desired levels. In another case (depending on the properties of the ore to be processed), the temperature of the reducing gas stream 20 might be too high and could be decreased intentionally with stream 54 to avoid overheating and resultant sticking of the DRI within  
20 the reactor.

Figure 3 also illustrates a fourth variation similar to the last, but wherein the hydrogen rich stream 54d is instead introduced to the lower part of the reduction reactor (cooling zone) by combination with the cooling gas stream 66. Even though  
25 this embodiment of the invention is very useful, it does not take

full advantage of the reducing potential of the hydrogen contained in stream 54d, because likely only a relatively small portion of stream 54d could be used in the reduction zone.

Figure 4, similar to Figure 2, shows how the present invention can be applied to an existing "self reformer" type installation. In this embodiment, the natural gas feed 36 can be diminished in quantity and potentially even eliminated by use of an alternative natural gas feed 36A to the cooling zone. In Figure 4, a full cooling recycle loop is illustrated, including the inlet 66 and outlet 68 of the cooling gas stream, the quench cooler 39, and the compressor 41. The natural gas feed 36A is to the gas inlet 66. Figure 4 also includes a connection 43 from the cooling gas loop to the reducing gas loop which can function as an indirect makeup gas external feed to the reducing zone (which could completely replace the feed in line 36).

Depending upon how the valves 35 and 37 are set, this can take any of a number of configurations. Of course, if one particular configuration is preferred, then the valves, piping and cooling loop elements can be included or omitted as appropriate. Other variations not specifically illustrated could be made, such as having compressor 41 positioned immediately after quench cooler 39 so that line 43 could feed downstream of compressor 32, rather than upstream.

Among the illustrated variations, if valve 37 is closed and valve 35 open, then the compressor 41 would be inoperative and



not needed. In such case, all of the natural gas added would be fed in through line 36A, pass through the cooling zone 14 (where some would be used for adjusting the carbon content of the hot descending DRI, some would be endothermically partially reformed in the presence of such DRI, a portion could flow upwardly from the cooling zone 14 already partially heated by the hot descending DRI for further reformation and use for reduction in the reducing zone 12, with the remainder passing externally from the reactor through outlet 68, cleaned and quench cooled in quench 39, pass on through open valve 35 in connecting line 43 and ultimately be fed to the reducing gas recycle loop at line 28.

An alternative configuration would be with both valves 35 and 37 open for those installations where the once-through flow of natural gas in the cooling zone 14 is insufficient and therefore recycling in the cooling loop is required.

A further configuration of Figure 4 would be with both valves 35 and 37 closed. This would be the equivalent of having only natural gas from line 36A feed through line 66 into the cooling zone 14 (with no cooling recycle) with all of such natural gas flowing upwardly into the reduction zone 12. This would insufficiently cool the exiting DRI 18 for cool discharge and would be alternatively too much cooled for hot discharged for briquetting or charging to an electric art furnace, if all of the natural gas feed were completely through line 36A. Consequently, a balance between a feed through line 36A and line 36 would



typically be made by appropriate adjustment to existing process conditions.

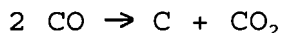
Figure 5 is very similar to Figure 4, but shows a further variation where line 43 connecting the cooling gas loop and the reducing gas loop instead of feeding into line 28 upstream of the compressor 32 and heater 34, instead feeds to line 20 downstream of the heater 34, thus requiring an auxiliary heater 34B (in those cases where the partial combustion of added oxygen at 60, would be insufficient or too disruptive of the gas composition fed in line 20 into the reducing zone).

The embodiment in Figure 6 is similar to the various embodiments illustrated in Figure 3 (wherein an "in line" reformer 40A is utilized) but further modified to have natural gas feed, preferably supplemental to feed 36, be to the cooling loop through line 36A.

Another advantage of the present invention results from the recycle stream having a higher content of hydrogen, which makes it possible to process a higher amount of gas due to the low heat capacity of hydrogen as compared to the heat capacity of the CO. This characteristic of hydrogen, allows one to process a larger amount of reducing gas through the gas heater or the reformer of a given size. Also, when one withdraws only CO<sub>2</sub> from the recycled gas stream 30 (as in most of the current prior art), the ratio between CO and CO<sub>2</sub> is increased to higher levels. That causes the gas to have a higher carburizing potential, which could



cause the metal dusting effect inside of the heater pipes or in the reformer pipes, due to the reaction:



5 Metal dusting a well known problem, which involves is an attack at process temperatures by carbon on the steel of the process equipment. With the present invention, the main component of the recycled stream is hydrogen, which avoids the metal dusting problems. It has been found that a ratio CO/CO<sub>2</sub> higher than 3 could cause carburizing problems in the thermal equipment, unless special alloys or inhibitors are used.

Another advantage of the invention that results from recycling mainly hydrogen, whose molecule is lighter than the CO, is in enabling a larger amount of recycle gas to pass through the reduction reactor and through the solid particles therein with a small increase in the pressure drop through said reactor and other equipment (such as the reformer or heater). With this advantage, the electric energy required by the compressor to circulate the reducing gas is decreased.

#### EXAMPLE

20 An example of the claimed process as calculated for potential implementation of an existing reduction system of the type illustrated in Figure 1 (but with a cooling gas loop and natural gas feed thereto, as in Figure 6). This is described as



follows. A reducing gas 46 produced in steam-natural gas reformer 40 has the following composition on a dry basis in volume %:

H<sub>2</sub>: 50% to 60%  
CO: 30% to 37%  
CO<sub>2</sub>: 2% to 3.5%  
CH<sub>4</sub>: 1% to 3%  
N<sub>2</sub>: 0% to 1.5%

with the rest being lesser amounts of other hydrocarbons and inert gases.

This gas is fed as make up to the reduction system as stream 46. About 50% of the top gas 26 from the reduction zone is diverted as stream 30, with a composition on a dry basis in volume % as follows:

H<sub>2</sub>: 35% to 45%  
CO: 18% to 25%  
CO<sub>2</sub>: 10% to 20%  
CH<sub>4</sub>: 2% to 4%  
N<sub>2</sub>: 0% to 3%.

This is compressed and passed through a PSA adsorption system 52. A gas stream 54 is obtained with a hydrogen content in volume% on a dry basis between of 92% and 99%. The recuperation of hydrogen from the gas stream 30 which is now used as chemical reductant instead of being used only as fuel, produces an increase in the rate of production of the reduction reactor in the best conditions up to about 50%.

From the foregoing description it should be apparent that the present invention provides a process capable of achieving the several objects of the invention set forth above. Thus it provides a novel and exceptionally efficient method of increasing

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the production capacity of existing reduction systems by advantageously utilizing hydrogen which in the prior art is purged and burned as fuel, instead of taking advantage of its chemical reducing potential.

5            Depending on the composition of the reducing gas to be treated for recovering its hydrogen content, approximately 40% by volume of the overall effluent gas treated is recycled. The rest of the effluent gas is burned as fuel.

As an example, if a reducing gas 30 has the following composition (by volume):

H<sub>2</sub>: 55%;  
CO: 21%;  
CO<sub>2</sub>: 15%;  
CH<sub>4</sub>: 6%;  
N<sub>2</sub>: 1%;  
H<sub>2</sub>O: 2%;

and is treated in a CO and CO<sub>2</sub> removal unit 52, the hydrogen rich stream 54 could contain: 95% to 100% by volume of H<sub>2</sub>; and the hydrogen poor stream 56 would be composed of:

H<sub>2</sub>: 25%;  
CO: 35%;  
CO<sub>2</sub>: 26%;  
CH<sub>4</sub>: 11%;  
N<sub>2</sub>: 1%;  
H<sub>2</sub>O: 2%;

From this, it can be seen that more than 75% of the H<sub>2</sub> content of the purge stream in this example is recovered for recycle and essentially all of the CO<sub>2</sub> content thereof is permanently purged. In another example, if the hydrogen rich stream is 98% H<sub>2</sub>, the



remaining 2% is CO, with only traces of other gases such as N<sub>2</sub> or CH<sub>4</sub>.

It is of course to be understood that the foregoing description is intended to be illustrative only and that numerous  
5 changes can be made in the structure of the system described and its operating conditions without departing from the spirit of the invention as defined in the appended claims.

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